Building AMERICA
Industrialized Housing Partnership

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The Building America Industrialized Housing Partnership (BAIHP):

Enhancing energy efficiency, durability and indoor air quality of industrialized housing

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ABSTRACT

The Building America Industrialized Housing Partnership project activities are described. Details are provided on causes and solutions to moisture problems in manufactured housing. Data is presented on field diagnostic tests conducted on six homes with moisture problems which show that problems arise because of one or more of the following factors -- low thermostat set points, leaky air distribution systems, lack of adequate return air paths, leaks in the belly board, inadequate crawl space ventilation, poor site drainage, clogged air conditioner drains, oversized air conditioners, presence of vinyl covered wall paper on the interior face of exterior walls.

Key Words: *Factory Built Housing, Moisture Problems, Energy Efficient Housing, Building America, U.S. Department of Energy*

1 INTRODUCTION

Of the two million homes built in the U.S. in 1999, over 18.5% were built in factories to the code of the U.S. Housing and Urban Development (HUD). These manufactured homes are one of the most affordable single family detached housing available any where in the world, generally costing less than $35/ ft^2 + land costs for centrally air conditioned and heated homes with built in kitchens. Available in all parts of the country, manufactured homes are more popular in the southern and western U.S. where land is still plentiful and in rural areas elsewhere.

Since 1995 the U.S. Department of Energy (DOE) has been funding four competitively selected research groups to foster technology-based innovations to increase the energy efficiency in U.S. housing. This program called Building America (http://www.eren.doe.gov/buildings/building_america/), achieves this through systems engineering of the whole house (concepts such as -- a more energy efficient envelope reduces the size and cost of the mechanical equipment realizing energy efficiency at little or no cost, attention to building science principles enhances quality and durability reducing call back costs etc.). In 1999, DOE competitively selected the BAIHP group to primarily serve the manufactured housing industry. Please visit us on the web at http://www.baihp.org/

2 BAIHP OVERVIEW

The Building America Industrialized Housing Partnership's goals are to:

1. Cost effectively reduce the energy cost of industrialized housing and portable classrooms by up to 50% while enhancing indoor air quality, durability and productivity.
2. Assist in the construction of thousands of energy efficient industrialized houses annually.
3. Make our team members pleased and proud to be working with us.

Industrialized housing includes manufactured housing (built to the HUD code), modular housing (factory built housing modules assembled on site) and production housing (site built housing produced in a systematic manner). The project scope also includes portable classrooms.

The Florida Solar Energy Center (FSEC) and the Department of Industrial Engineering of the University of Central Florida (UCF) serve as the prime contractor. Subcontractors include the Washington State University Energy Program, the American Lung Associations of Central Florida, the Oregon Office of Energy, the Idaho Department of Water Resources, Florida Home Energy and Resources Organization and D.R. Wastchack, LLC.

Builder team members include:
• American Energy Efficient Homes and Investments Inc. (Production builder)

- Atlantic Design and Construction (Production builder)
- Barker-Coleman Communities
- Beck Builders (Production builder)
- Cavalier Homes (HUD code manufacturer)
- Centex Homes (Production builder)
- Fallman Design and Construction
- Fleetwood Homes (HUD code manufacturer)
- G.W. Robinson (Production Builder)
- Habitat for Humanity International (Affordable housing builder)
- Neuffer Homes and Development (Production Builder)
- Palm Harbor Homes (HUD code manufacturer)
- Pruett Builders (Custom builder)
- Southern Energy Homes (HUD code manufacturer)
- Town and Country Homes of Texas (HUD code manufacturer)
- Valley Manufactured Housing (HUD code manufacturer)

We collaborate with 20 additional supplier and non profit team members. The partnership collaborates closely with two other Building America teams - Building Science Consortium and the Hickory Consortium. The partnership is part of the DOE - PATH (Partnership for Advancing Technology in Housing) collaboration.

The U.S. Department of Energy provides primary funding for the project. Matching funds are provided by the Florida Department of Community Affairs and the Northwest Energy Efficiency Alliance. The project period is Septemeber 1999 - October, 2004.

The primary project tasks for 2001 are described below:

TASK 1. TECHNICAL ASSISTANCE AND RESEARCH

Subtask 1.1 Technical Assistance

The overall objective of this subtask is to assist in the construction of at least 4,000 energy efficient, healthy and durable homes per year. The vast majority of these (at least 75%) will be factory built homes.

FSEC will provide technical assistance to industrialized homebuilders (HUD Code, modular, panelized, precut, etc.), Habitat for Humanity affiliates, site builders not served by other BA teams, and manufacturers of innovative components and construction systems to build energy efficient, durable housing. Primary emphasis will be to serve existing factory builder partners (Palm Harbor Homes, Fleetwood homes, Southern Energy Homes, Cavalier Homes, Town and Country homes of Texas) but assistance will also be provided to existing site builder partners and new partners as time and budgets permit. Technical assistance activities include design reviews with the Building America systems engineering approach, energy analysis for Energy Star compliance, diagnostic testing in the plant and in the field, training of line workers, assisting in sales training regarding Energy Star homes, developing joint programs with supplier partners (e.g. Engineered for Life) and related activities. At least 12 site visits will

be conducted.

FSEC will conduct whole house systems analysis using the software EnergyGauge® USA and make recommendations on cost effective options for optimum levels of energy conservation in manufactured housing in various climatic zones of the USA.

Existing subcontractor Florida Home Energy and Resources Organization (FLHero) will work with about a dozen builders and developers, primarily in the Gainesville, FL area. FLHero assisted homes include single and multifamily units incorporating ductwork in conditioned space, radiant barriers, high efficiency mechanical equipment and other energy efficient technologies.

Existing subcontractor D.R. Wastchak, will provide design and testing services to over one dozen builders, primarily in the Phoenix, AZ area to build, rate and certify Energy Star homes.

Existing subcontractor Washington State University Energy Program (WSU), together with 2nd tier subs (Oregon Energy Office and Idaho Division of Energy Resources) will continue to support the Super Good Cents/ Natural Choice (SGC/NC) program in the Pacific Northwest. Technical assistance activities include conducting quarterly duct testing and inspections in Valley, Fleetwood and other manufactured housing factories, continued refinement of SGC/NC standards, filed testing of problem homes, evaluation of new components, supporting BPA and other demonstration houses, participating in quarterly meetings with Washing State's manufactured housing technical work group and related activities. This activity should result in the production of about 3,000 manufactured homes a year.

WSU will also undertake a comprehensive analysis of energy savings from revised energy and ventilation specifications of the SGC/NC program.

UCF Industrial Engineering department will provide technical assistance to the Building America Hickory consortium industry partners (Excel homes and Cardinal homes) in design and implementation of their new factories by analyzing the factory layout and performance. UCFIE will also recommend new applications of computer technology for the factory floors and analyze callback demands from customers.

Other technical assistance and analysis will be also conducted. Examples include FSEC providing technical assistance (design analysis, field tests etc.) to the Miami Hope VI inner city redevelopment project. It is also planned to have North Carolina A & T University (NCATU) perform an analysis to determine optimum applications of autoclaved aerated concrete (AAC) in manufactured housing.

Educational and outreach activities will include participating in several national conferences (ASHRAE, EEBA, MHI/MHRA, Energy 2001, ASHRAE IAQ and others). Collaborations will continue with Habitat for Humanity to conduct a survey of Habitat Energy Star homes, publishing design options on the web for meeting Energy Star levels in Habitat homes and assist in conducting regional and national training workshops. Collaborations will continue with other Building America teams, NREL, ORNL, LBNL, PNNL, INEEL, NAHB, PATH and others on project related tasks as opportunities arise.

Subtask 1.2 Moisture Research

FSEC will conduct this subtask to eliminate moisture problems plaguing HUD Code homes in the Southeast through the following activities:

Design and procure a manufactured housing lab (MHLab) which is cost shared by industry. The purpose of this lab is to conduct training as well as systems research activities. It is planned to acquire a flexible energy efficient double wide incorporating two different air duct systems and at least two different HVAC units. Thus it will be able to simulate real life conditions in a wide variety of manufactured home designs. The MHlab will be located on the FSEC campus.

Conducting diagnostic tests in problem homes, fixing problem homes, evaluating the effectiveness by conducting pre/post fix short term tests, and related activities. At least 15 problem homes will be investigated. In cooperation with Blue Sky Foundation , or other subcontractors to be determined, conduct additional field measurements in problem or base case manufactured homes.

Performing systems research tests and analysis on subfloor and belly construction practices, ventilation practices, factory installed HVAC equipment, alternative duct layout and construction practices and related areas. Findings to be presented to partners and in industry meetings as well as technical and trade conferences and articles.

Develop moisture control training models, visual aids and related web sites and papers. Deliver training to industry partners in the MHLab or at partner sites.

Collaborate with HUD, State inspection agencies, NCSBCS, MHI, MHRA and others in these areas.

Subtask 1.3 Field monitoring

The objective of this subtask is to document energy savings and related environmental parameters on prototype and production houses through long term instrumented monitoring. Primarily an FSEC task.

FSEC will continue monitoring of the energy efficient and base case side-by-side houses on NCATU campus for a full year and demonstrate attainment of the Building America goal of 50% energy savings for manufactured homes.

FSEC will perform monitoring on the David Hoak energy efficient residence and a comparable base case residence to showcase cost effective energy conservation at the Building America level.

FSEC will instrument and monitor the Insider® and a conventional air conditioner at the Palm Harbor Homes / Plant City model center. Purpose is to determine the performance of this innovative heat pump (Insider)

With WSU assistance, FSEC will collect data from the demo house at the Cle Elum, WA fish facility.

FSEC and WSU will jointly continue to collect and analyze data from the WSU Energy house on a variety of HVAC and lighting options.

FSEC will continue research on cool roofs at its flexible roof facility (investigate unpainted galvanized metal and possibly other roofs) and in the seven Habitat for Humanity occupied homes in Ft. Myers, FL (investigate light colored roofing on the sealed attic and possibly other strategies)

During the summer of 2001, additional field monitoring may be conducted in cooperation with utilities on various load saving strategies. Another important research question is to quantify the cooling effect of slab or tile floors as opposed to carpeted slab on grade floors. An attempt will be made to find a willing builder partner and conduct this experiment in two identical homes or test cells.

Subtask 1.4 Healthy and Green Housing

The objective of this subtask is to conduct activities to advance the science and engineering and analysis capabilities so that an increasing share of industrialized housing is healthy and green (resource efficient). This is primarily an FSEC task.

Existing subcontractor, ALA of Central Florida will establish the framework for providing Healthy Remodel Guidelines through working with the Johnston remodel. Provide marketing assistance and set up an educational workshop and open house during the project.

ALACF and FSEC will participate in developing the technical standards and program implementation guidelines of the ALA national guidelines for Health House®.

FSEC will collaborate with the Florida Green Building Coalition, national green groups and related organizations to develop and/or refine green home standards, participate in educational programs, assist in demonstration housing and conduct related activities.

FSEC will continue work on Energy Gauge® USA, a DOE2.1E based home energy rating and analysis software. Emphasis will be on increasing accuracy and user friendliness.

FSEC plans to assist in development and monitor a "super house" created by Fallman Design and Construction, a site builder partner in Central Florida. Energy efficiency, optimized ventilation, passive and active solar features, and affordablity will be key features of this house.

TASK 2. PORTABLE CLASSROOMS

The objective of this task is to provide technical assistance to portable classroom manufacturers, school districts and related organizations interested in improving the quality of learning and energy efficiency of portable classrooms. This is primarily a WSU (and its subcontractors Oregon and Idaho) task.

The WSU team will develop procurement standards for new and retrofit portable classrooms.

The WSU team will facilitate the continued data collection from the existing instrumented classrooms in ID and WA. PNNL, through separate funding will continue to collect the data and FSEC will continue to post the data on the web as is being currently done. Data analysis will be WSU and PNNL responsibility. The WSU team will procure and site another energy efficient classroom in OR. PNNL will instrument it and FSEC will provide web hosting services for the

data. The WSU team will develop and administer a survey for occupants of the instrumented classrooms. They will also collect and analyze available historical data on existing portables and conduct short term diagnostic tests on some portables.

The WSU team will make numerous site visits to manufacturers and school districts. The objective will be to provide technical assistance and education in energy efficiency and daylighting techniques. WSU will convene a 2nd workshop for all interested parties. The WSU team will also conduct a revised technical and economic analysis of energy efficiency measures for portable classrooms.

UCFIE will assist one manufacturer by visiting their manufacturing facility and making recommendations to improve productivity through industrial engineering analysis and simulation tools. WSU will arrange the introductions for this visit.

Subject to cooperation from Southern California Edison (SCE), FSEC plans to instrument the SCE demonstration portable classroom located on SCE property. The data from the classroom will be made available on the web.

TASK 3. PROJECT MANAGEMENT, REPORTING

The project manager will coordinate closely with DOE headquarters and DOE Golden program managers. Monthly reports will be prepared. A final report for the second budget period will be prepared.

The project web page will be updated regularly. Well illustrated colorful one pagers on completed tasks or major project activities will be prepared. At least 5 of these will be prepared.

BAIHP personnel will plan to participate in DOE project review (Building America or other) meetings as invited.

In addition one project review meeting is planned where DOE, team members and other collaborators will be invited.

3 MOISTURE PROBLEMS IN MANUFACTURED HOMES

Moisture problems are being experienced by a significant number of manufactured homes in the hot, humid climate of the Southeast U.S. Moisture problems include extensive mold, soft wallboard, buckled floors and high relative humidities in the home. Frequently, these homes have a high air-conditioning bill

as homeowners attempt to increase comfort by lowering the temperature and each degree F drop in temperature causes an approximate 10% increase in cooling costs. The BAIHP team has investigated over 25 problem homes and have found that the problems are caused by the following factors acting individually or in combination - low thermostat set points, leaky air distribution systems, lack of adequate return air paths, leaks in the belly board, inadequate crawl space ventilation, poor site drainage, clogged air conditioner drains, oversized air conditioners, presence of vinyl covered wall paper on the interior face of exterior walls.

3.1 Building Science Basics for Moisture Plagued Homes

Figure 1: Manufactured Home Production

Fig. 1 shows photo of one-half of a manufactured home just produced by the factory. These homes have a permanent steel chassis attached below the floor. After production the homes could travel a few hundred miles, hauled by a truck, before set up in its final location. The homes are set up by placing blocks under the steel I-beams and anchoring the steel beams to the ground firmly. A skirting covers the blocks and steel frame in a fully set up home (Fig. 2 and 3)

Figure 2: A Fully Set Up Two-Section Manufactured Home

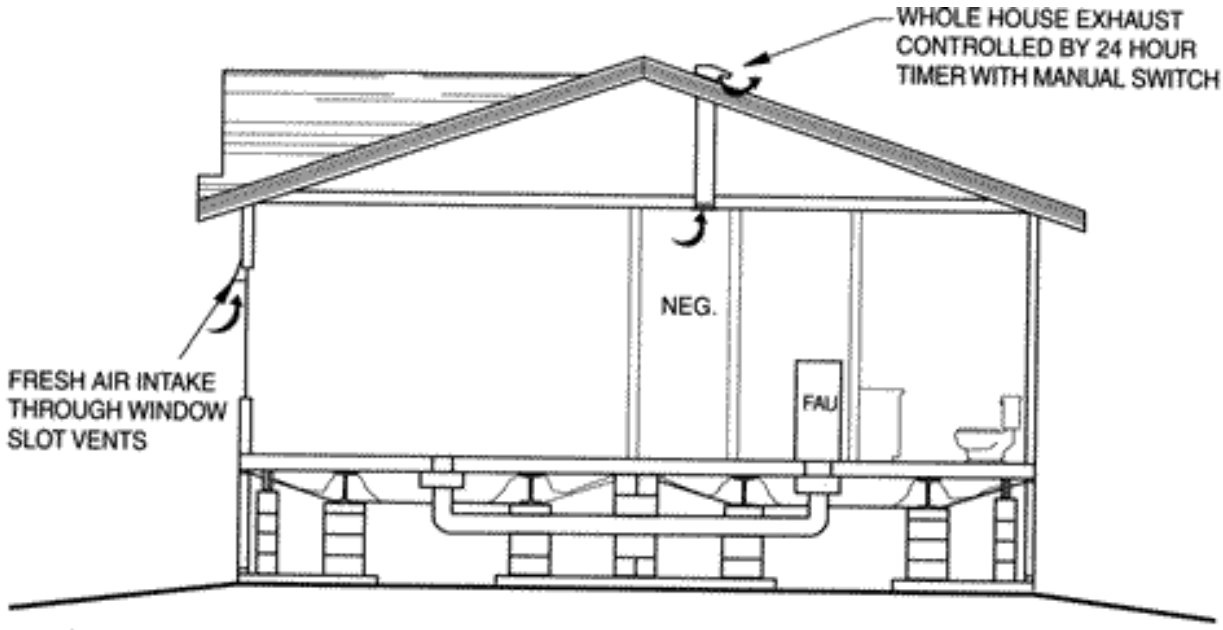

Figure 3: Cross section view showing foundation support, crossover duct and one type of ventilation system in a manufactured home. (Illustration credit: 1997 Northwest Energy Efficient Manufactured Home Program In-Plant Inspection Manual)

Manufactured homes are typically heated or cooled by a system of ductwork, which delivers hot or cold air from the air handler unit (AHU). The ductwork can be in the attic or in the belly cavity of the home. Fig. 4 shows the ducts in the belly, supplying conditioned air to all rooms through floor vents. This is a very common system in manufactured homes.

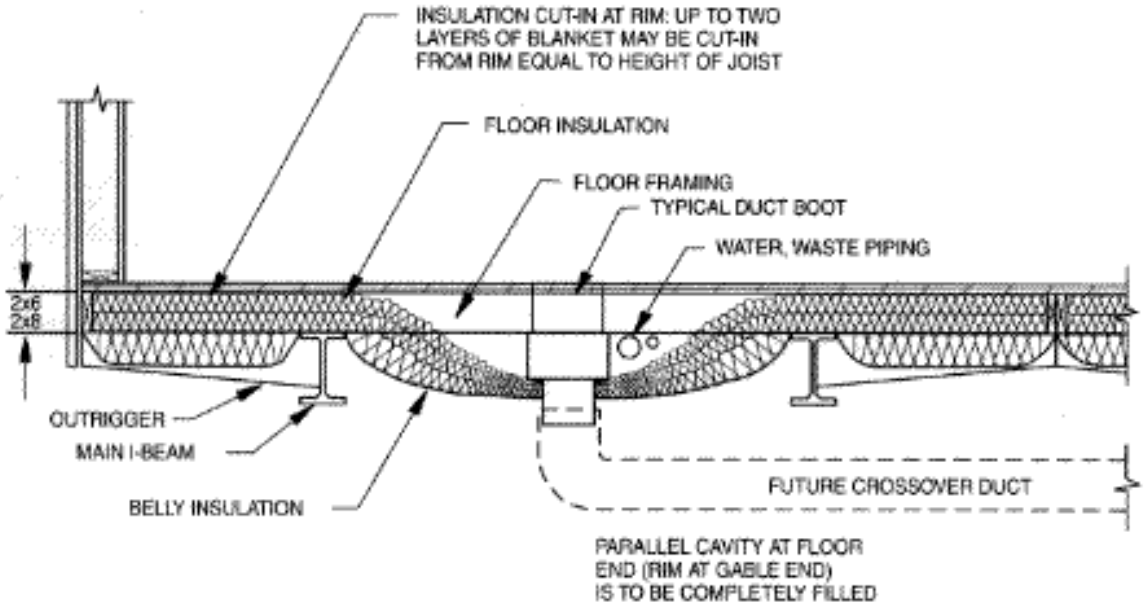

Figure 4: Detail of the Floor and Belly Area
(Illustration credit: 1997 Northwest Energy Efficient Manufactured Home Program In-Plant Inspection Manual)

The ducts are typically made out of Aluminum or Fiberglass trunk lines which supply air to the floor registers through in-line boots or through flex ducts, which terminate to perimeter registers on the floor.

One of the biggest causes of moisture problems in manufactured homes is leakage in supply ducts. The leakage is caused because of poor design and construction practices which leaves holes at the connection points of the AHU to the main trunk, the boots to the trunk, the boots to the supply registers, end caps, cross-over duct connections and other connection points in the duct work. When the AHU blows air, some of it leaks into the belly and eventually to the outside through tears in the belly board. This loss of air creates a negative pressure inside the house and a positive pressure in the belly as schematically shown in Fig. 5. The negative pressure draws outside or attic air into the house through the numerous cracks and crevices connecting the inside of the house to the outside or the attic. If this outside air is cold and dry, like it is in the wintertime in the Northern U.S. it will increase the heating energy use and occupant discomfort. But it will not rot the house.

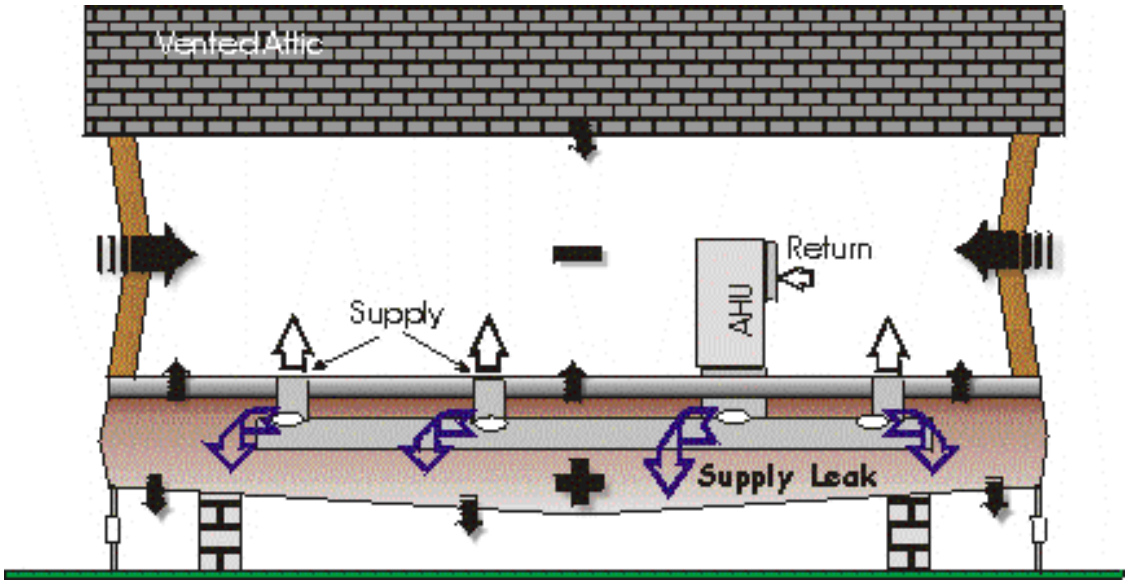

Figure 5: Pressure Field and Unintentional Airflows Created by Supply Duct Leaks

In the hot, humid Southeastern U.S. the air is consistently above a dewpoint of 75°F or more during the summer months. If the homeowner decides to keep the home below 75°F (which some do, especially in homes with oversized air conditioners which do not dehumidify well) then the moisture laden air from the outside can come into contact with cold inside surfaces and condense. If it condenses behind an impermeable surface such as vinyl flooring or vinyl wallpaper, serious mold, mildew problems and floor buckling problems can result.

Another aggravating factor is the lack of return air transfers when interior doors are closed. In many manufactured and site built homes there is only a single return and very small amounts of return air transfers (basically the undercut at the bottom of interior doors). When interior doors are closed (e.g. for privacy) the bedrooms become pressurized and the main body of the house depressurizes. This adds to the depressurization of the main body of the house from leakage in supply air ducts.

It is important to note that we are talking about miniscule amounts of negative pressures - on the order of 1 to 3 Pascals. However, over time, even these tiny air pressures can cause serious damage.

Figure 6: Duct Leakage Test Conducted in the Factory Yard
on one Section of a Manufactured Home

The amount of duct leakage is measured by a calibrated fan, called a duct-blaster. The duct-blaster is attached to the return grill or the crossover duct opening (Fig. 6) and all the supply registers are masked off. Then the fan is operated to bring the ductwork at -25Pa and the airflow through the fan read in cubic feet per minute (CFM). This is called the total duct leakage. In good air - tight ductwork the total duct leakage (CFM@25Pa) should be below 6% of the floor area measured in square feet. Fig. 6 shows this type of testing being done at the manufacturing facility.

Another duct leakage measurement is also conducted. This is the duct leakage to outside, measured by depressurizing the whole house to -25Pa by a blower door and adjusting the duct- blaster flow such that there is no pressure difference between the house and the ducts. This measurement is a true indicator of duct air loss to the outside and the number used in energy calculations to estimate the energy loss from leaky ducts. Good duct systems typically have ducts to out in CFM < 3% of the floor area in square feet.

The battery of tests run by BAIHP researchers in a problem house include measuring the airtightness of the whole house by a blower door, depressurizing the house to -50 Pa. At that time the house to belly and belly to crawlspace pressures can also be measured. We also test pressure differentials caused by AHU

operation and interior door closures. In addition, another measurement of duct leakage, called pressure pan, is conducted on some houses to pinpoint the specific registers which might be leaking badly. In this measurement the house is first depressurized to -50 Pa. All the register vents are unmasked. Then each register is covered one by one and the pressure difference between the covered register and the house is measured. A zero reading implies zero leakage at that register. Readings over 1 Pa indicate a good sized leakage which should be repaired.

3.2 Field Test Results

Over 25 homes with moisture problems have been field tested by BAIHP researchers. Table 1 provides observed and measured data from several homes.

Table 1 Field test results from 6 problem homes

	Home 1	Home 8	Home 10	Home 11	Home 13	Home 14
Test Date	10/1/98	7/17/00	8/14/00	8/25/00	9/13/00	9/14/00
Location	Prairiville, LA	Ft. Lauderdale, FL	Tampa, FL	Orlando, FL	Pt. Fourchon, LA	Houma, LA
Manufacturer Code	C	B	B	D	E	E
Age of Home when tested	3 yrs		1 yr	<1 yr		
Single, Double or Triple wide	Double		Double		Single	Double
House Size #BR/BA or sq. ft.	3BR/2BA	1492	2000	900	1008	1792
House site well shaded?	Y	N		N	N	
Observed Moisture Problems						
Odors?	Y		Y	N		
Interior RH>65%	N		Y	Y		N
Soft Walls?	Y		Y	N	Y	Y
Mold present?	Y	Y (under vinyl floor)	Y (closets, bath)	N		
Buckled floors under vinyl?	N		Y (severe)	Y		
Stains/Rust/Condensation			Y			Y
Bowed/Buckled Walls						
Visual/Interview Findings						
Interior Temperatures	68-70F	75-80F	73	72-80F	69-72F	71F

High exhaust fan or dryer use?	Y		Y	N		
Problem walls vinyl covered?	Y	Y		Y		
AHU always on?	N		N	Y		
Poor crawlspace venting?	N		Y	Y		
Poor site drainage?	Y		Y	N	Y	Y
Tears in belly board?	Y	Y	Y		Y	Y
Ground cover absent?	N			Y	Y	Y
Poor condensate drainage?	N		Y	N		
Dryer duct dumping to crawl?	N		N	N		
MBR door typically closed?	Y	Y	N	N	Y	
Unbalanced airflows?			Y		Y	
Unsealed marriage line?						Y
Air conditioner tonnage			4			
Dirty AHU coil?			Y			
Diagnostic Test Results						
House CFM50	2453		2000	835	1187	3967
CFM60/sq.ft.			1.0	0.9	1.2	2.2
ACH50		6.6	7.5	7.0		
Duct Leak, total CFM@25Pa	184		112	114	286	510
Total D.L. as % of floor area			5.6	12.7	28.4	28.5
Duct Leak to out, CFM@25Pa	134		26	48	229	505
D.L. to out as % of floor area		2.3	1.3	5.3	22.7	28.2
Pressure pan av, supply			0.1		1.55	2.94
Pressure pan av, return						
Hse-Belly, Hse @-50Pa				-36.4		
Belly-Crawl, Hse @-50Pa				-16		
Hse-Attic, Hse @-50Pa						
Pressure mapping (Pa)						
House to Out, ahu off	0.1				0	
Hse-Out, ahu on, doors open	-0.3	0	0.5 to 0	-0.5	-2.5	-1.8
Hse-Out, MBR closed	-1.4	-2.2	-0.5	-2.5 to -3		
Hse-Out, all Brs or all int. doors closed		-2.6	-1.2	-2.5 to -3	-4.5	
MBR-LR, door closed	5.2	5.3	5.5	6.5	17.0	2.9
BR2-LR, door closed	5.1	6.4	1.4		1.5	2.4

BR3-LR, door closed	3.6	4.4	2.4		2.2	0.8
Other Comments	C1, C2, C4	C7		C9	C2, C10	C10

C1: House had extra vents in walls and/or roofs as an ill conceived moisture control measure.

C2: House interior wall board was repaired/replaced before.

C3: House floors repaired/replaced before.

C4: House had both vinyl covered and tape and textured wall board. Problems seem only on vinyl covered exterior walls.

C5: Very high utility bills >$200 up to $500/month.

C6: Extra window a/c added as house could not be cooled.

C7: Mold on floor on cold spot directly under register.

C8: Return duct disconnected at the outdoor unit.

C9: Unoccupied home (model center).

C10: AHU coils and/or filters dirty.

C11: One room had animal care facility and large exhaust running at all times.

C12: Supply flex fallen of from time to time.

4 CONCLUSIONS

The BAIHP project conducts a wide range of activities to meet its goals. The reader is invited to visit the project web page http://baihp.org to view the current status of the various activities.

In the moisture control area it is clear that a combination of factors cause moisture damage in manufactured homes. BAIHP researchers are continuing to work with industry team members to solve moisture problems through recommendations in the design (provision of return air transfers and appropriate ventilation systems, proper sizing of air conditioning equipment and duct systems, adequate venting of crawl spaces etc.), construction (proper assembly of duct systems emphasizing sealed connection points), operation (homeowner instructions) and training of factory personnel in causes and cures to moisture problems.

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